EXHIBIT 6

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Al-Ali

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(54) **PHYSIOLOGICAL MONITORING DEVICES, SYSTEMS, AND METHODS**

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(58) **Field of Classification Search**

None

See application file for complete search history.

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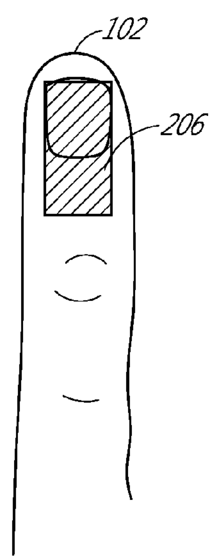
(57) **ABSTRACT**

A non-invasive, optical-based physiological monitoring system is disclosed. One embodiment includes an emitter configured to emit light. A diffuser is configured to receive and spread the emitted light, and to emit the spread light at a tissue measurement site. The system further includes a concentrator configured to receive the spread light after it has been attenuated by or reflected from the tissue measurement site. The concentrator is also configured to collect and concentrate the received light and to emit the concentrated light to a detector. The detector is configured to detect the concentrated light and to transmit a signal representative of the detected light. A processor is configured to receive the transmitted signal and to determine a physiological parameter, such as, for example, arterial oxygen saturation, in the tissue measurement site.

25 Claims, 7 Drawing Sheets



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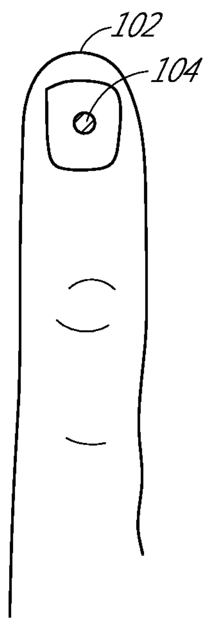


FIG. 1
(PRIOR ART)

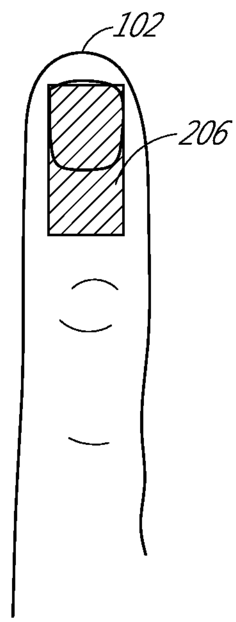


FIG. 2

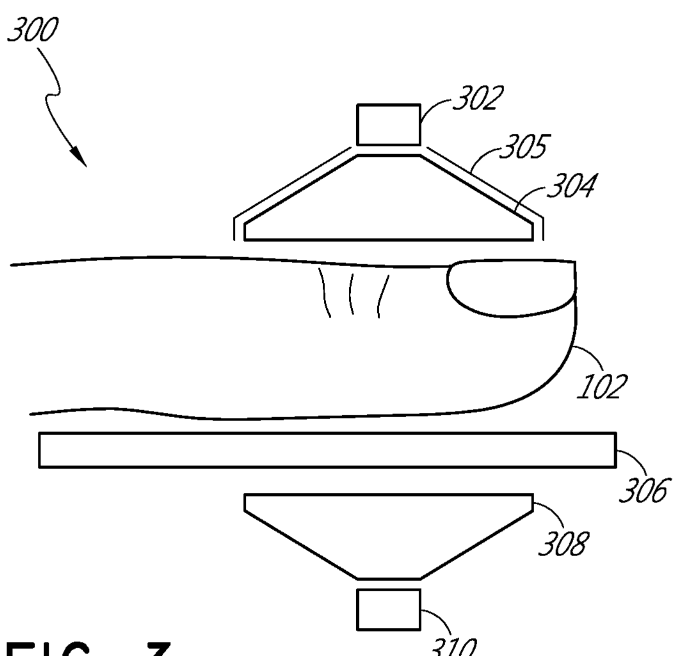


FIG. 3

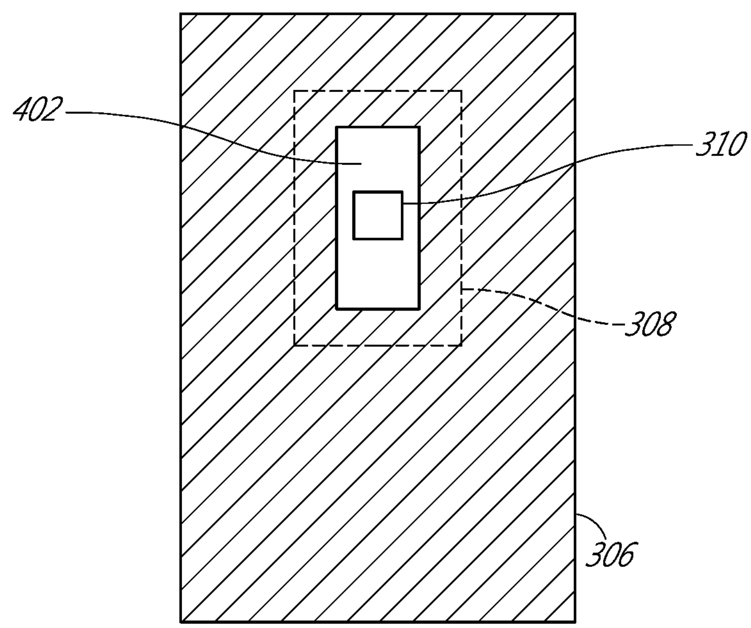


FIG. 4A

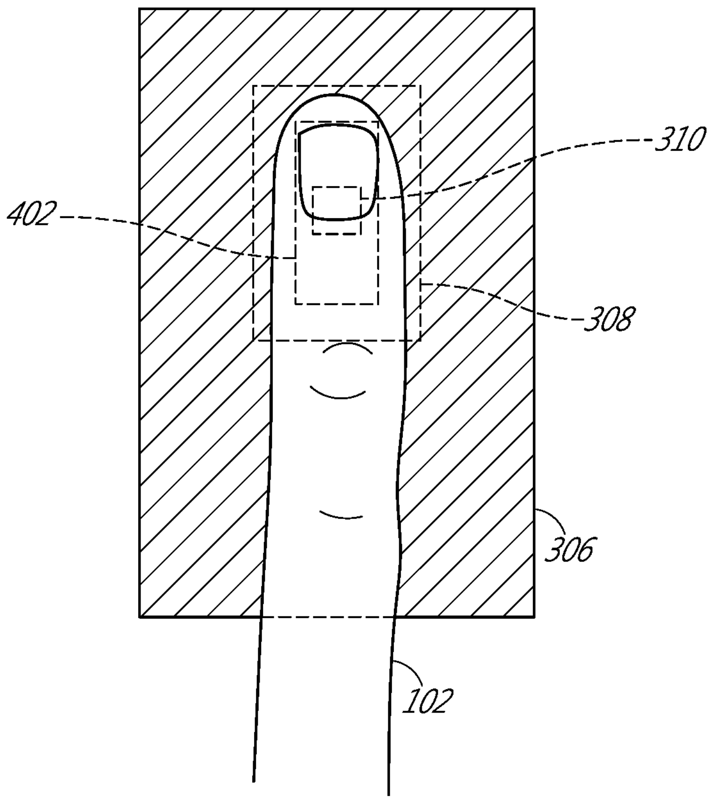


FIG. 4B

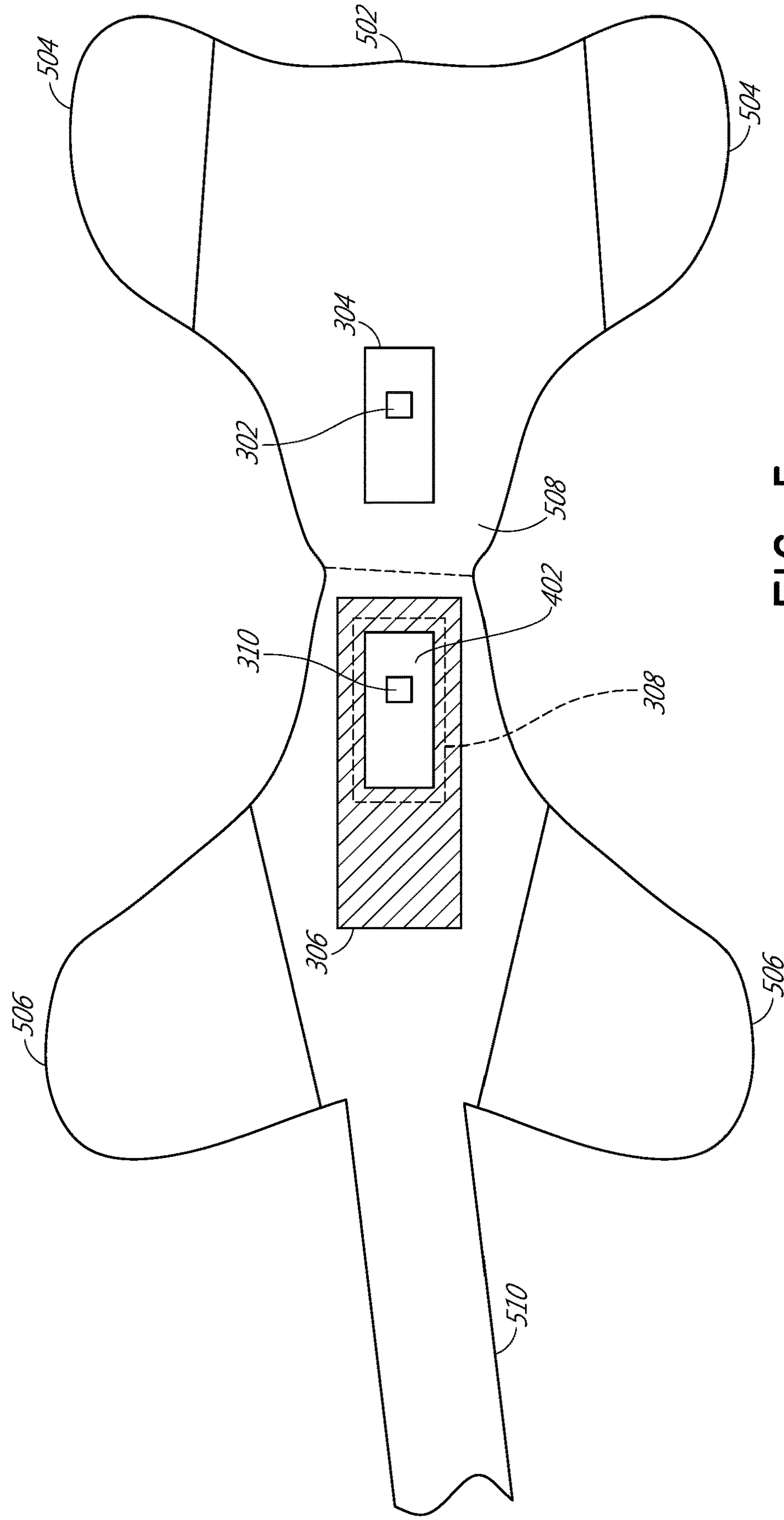


FIG. 5

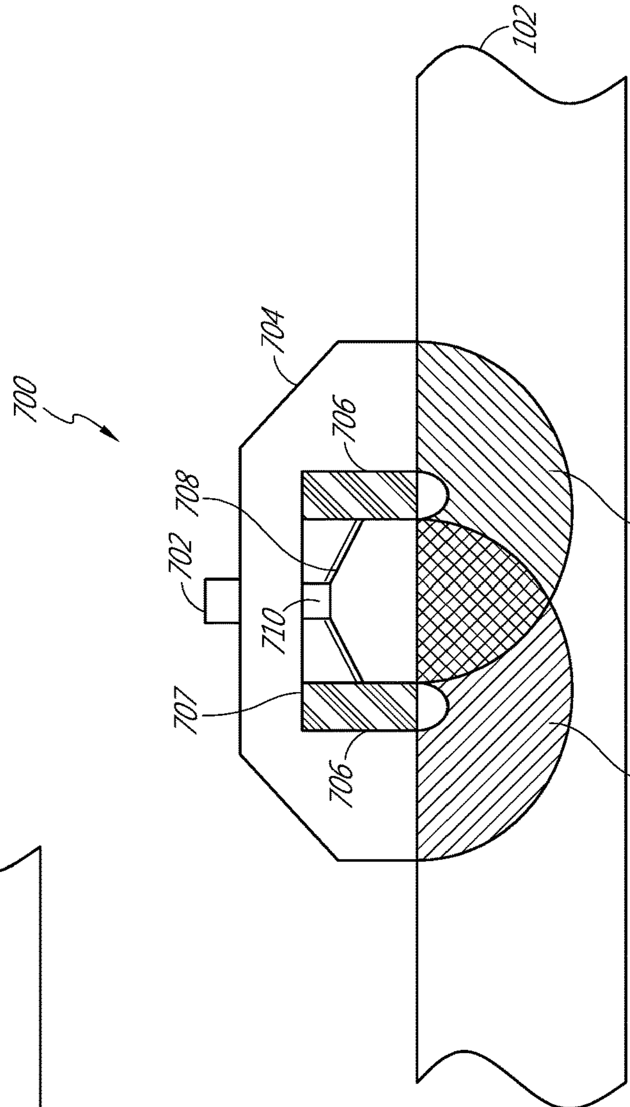


FIG. 7A

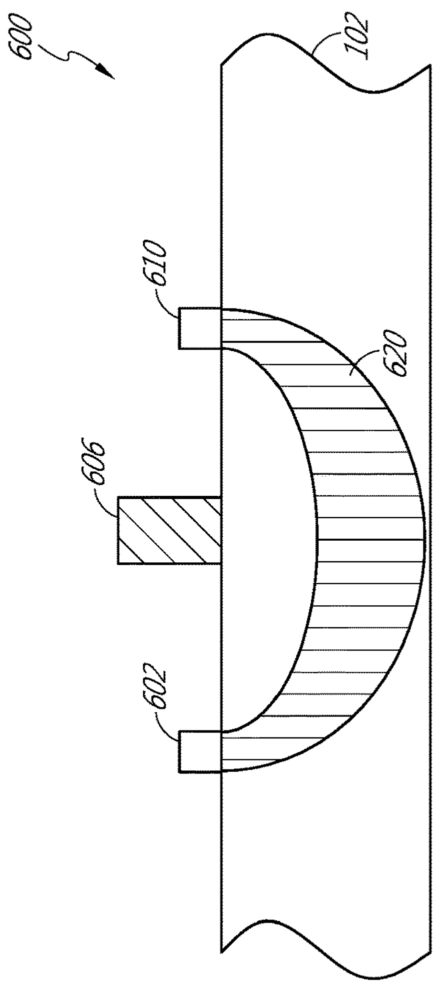


FIG. 6
(PRIOR ART)

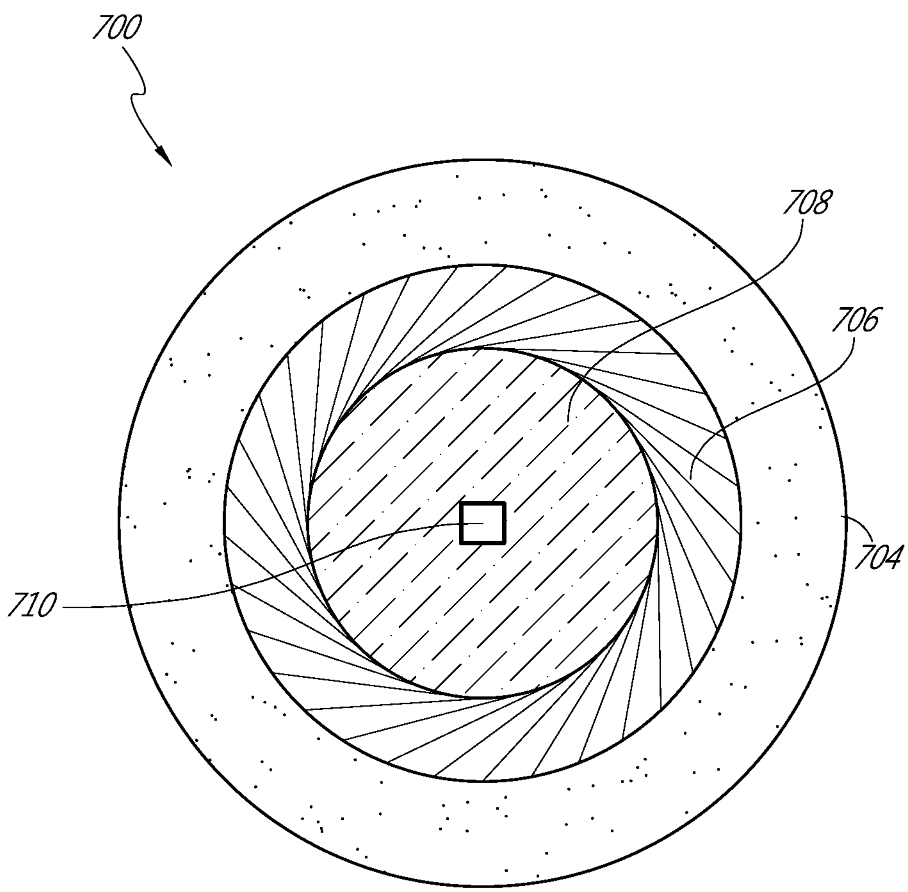
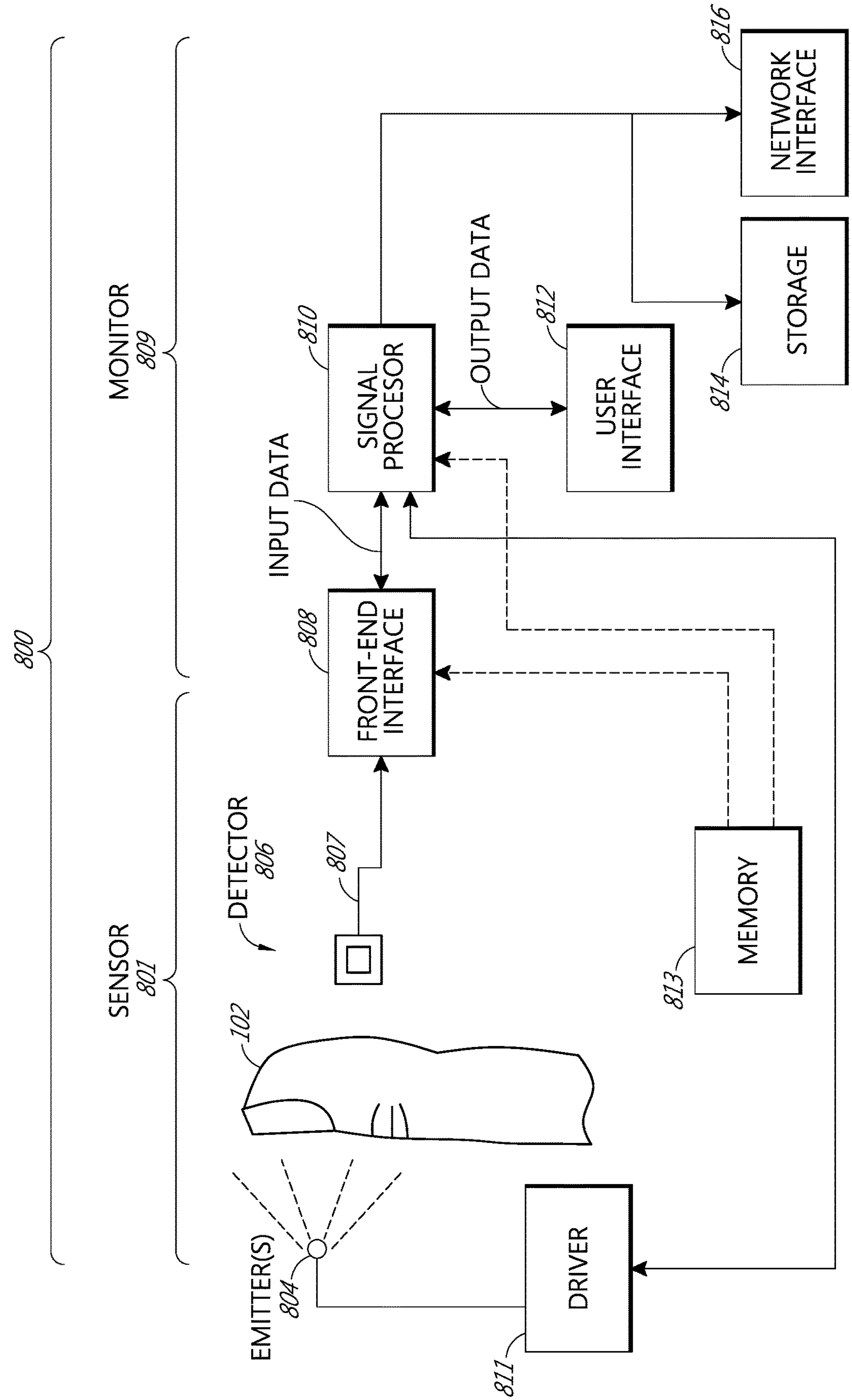


FIG. 7B



800
MONITOR
809
SENSOR
801
NETWORK INTERFACE
816
STORAGE
814
OUTPUT DATA
SIGNAL PROCESOR
810
USER INTERFACE
812
INPUT DATA
FRONT-END INTERFACE
808
DETECTOR
806
807
MEMORY
813
102
EMITTER(S)
804
DRIVER
811

FIG. 8

PHYSIOLOGICAL MONITORING DEVICES, SYSTEMS, AND METHODS

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 16/532,065 filed Aug. 5, 2019, which is a continuation of U.S. patent application Ser. No. 16/226,249 filed Dec. 19, 2018, which is a continuation of U.S. patent application Ser. No. 15/195,199 filed Jun. 28, 2016, which claims priority benefit under 35 U.S.C. § 119(e) from U.S. Provisional Application No. 62/188,430, filed Jul. 2, 2015, which is incorporated by reference herein. Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

FIELD OF THE DISCLOSURE

The present disclosure relates to the field of non-invasive optical-based physiological monitoring sensors, and more particularly to systems, devices and methods for improving the non-invasive measurement accuracy of oxygen saturation, among other physiological parameters.

BACKGROUND

Spectroscopy is a common technique for measuring the concentration of organic and some inorganic constituents of a solution. The theoretical basis of this technique is the Beer-Lambert law, which states that the concentration C, of an absorbent in solution can be determined by the intensity of light transmitted through the solution, knowing the pathlength d_λ, the intensity of the incident light $I_{0,\lambda}$, and the extinction coefficient $\varepsilon_{1,\lambda}$ at a particular wavelength A.

In generalized form, the Beer-Lambert law is expressed as:

$$I_\lambda = I_{0,\lambda} e^{-d_\lambda \cdot \mu_{a,\lambda}} \tag{1}$$

$$\mu_{a,\lambda} = \sum_{i=1}^{n} \varepsilon_{i,\lambda} \cdot c_i \tag{2}$$

where $\mu_{\alpha,\lambda}$ is the bulk absorption coefficient and represents the probability of absorption per unit length. The minimum number of discrete wavelengths that are required to solve equations 1 and 2 is the number of significant absorbers that are present in the solution.

A practical application of this technique is pulse oximetry, which utilizes a noninvasive sensor to measure oxygen saturation and pulse rate, among other physiological parameters. Pulse oximetry relies on a sensor attached externally to the patient to output signals indicative of various physiological parameters, such as a patient's blood constituents and/or analytes, including for example a percent value for arterial oxygen saturation, among other physiological parameters. The sensor has an emitter that transmits optical radiation of one or more wavelengths into a tissue site and a detector that responds to the intensity of the optical radiation after absorption by pulsatile arterial blood flowing within the tissue site. Based upon this response, a processor determines the relative concentrations of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb) in the blood so as to derive oxygen saturation, which can provide early detection of potentially hazardous decreases in a patient's oxygen supply.

A pulse oximetry system generally includes a patient monitor, a communications medium such as a cable, and/or a physiological sensor having one or more light emitters and a detector, such as one or more light-emitting diodes (LEDs) and a photodetector. The sensor is attached to a tissue site, such as a finger, toe, earlobe, nose, hand, foot, or other site having pulsatile blood flow which can be penetrated by light from the one or more emitters. The detector is responsive to the emitted light after attenuation or reflection by pulsatile blood flowing in the tissue site. The detector outputs a detector signal to the monitor over the communication medium. The monitor processes the signal to provide a numerical readout of physiological parameters such as oxygen saturation (SpO2) and/or pulse rate. A pulse oximetry sensor is described in U.S. Pat. No. 6,088,607 entitled Low Noise Optical Probe; pulse oximetry signal processing is described in U.S. Pat. Nos. 6,650,917 and 6,699,194 entitled Signal Processing Apparatus and Signal Processing Apparatus and Method, respectively; a pulse oximeter monitor is described in U.S. Pat. No. 6,584,336 entitled Universal/Upgrading Pulse Oximeter; all of which are assigned to Masimo Corporation, Irvine, Calif., and each is incorporated by reference herein in its entirety.

There are many sources of measurement error introduced to pulse oximetry systems. Some such sources of error include the pulse oximetry system's electronic components, including emitters and detectors, as well as chemical and structural physiological differences between patients. Another source of measurement error is the effect of multiple scattering of photons as the photons pass through the patient's tissue (arterial blood) and arrive at the sensor's light detector.

SUMMARY

This disclosure describes embodiments of non-invasive methods, devices, and systems for measuring blood constituents, analytes, and/or substances such as, by way of non-limiting example, oxygen, carboxyhemoglobin, methemoglobin, total hemoglobin, glucose, proteins, lipids, a percentage thereof (e.g., saturation), pulse rate, perfusion index, oxygen content, total hemoglobin, Oxygen Reserve Index™ (ORI™) or for measuring many other physiologically relevant patient characteristics. These characteristics can relate to, for example, pulse rate, hydration, trending information and analysis, and the like.

In an embodiment, an optical physiological measurement system includes an emitter configured to emit light of one or more wavelengths. The system also includes a diffuser configured to receive the emitted light, to spread the received light, and to emit the spread light over a larger tissue area than would otherwise be penetrated by the emitter directly emitting light at a tissue measurement site. The tissue measurement site can include, such as, for example, a finger, a wrist, or the like. The system further includes a concentrator configured to receive the spread light after it has been attenuated by or reflected from the tissue measurement site. The concentrator is also configured to collect and concentrate the received light and to emit the concentrated light to a detector. The detector is configured to detect the concentrated light and to transmit a signal indicative of the detected light. The system also includes a processor configured to receive the transmitted signal indicative of the detected light and to determine, based on an

amount of absorption, an analyte of interest, such as, for example, arterial oxygen saturation or other parameter, in the tissue measurement site.

In certain embodiments of the present disclosure, the diffuser comprises glass, ground glass, glass beads, opal glass, or a microlens-based, band-limited, engineered diffuser that can deliver efficient and uniform illumination. In some embodiments the diffuser is further configured to define a surface area shape by which the emitted spread light is distributed onto a surface of the tissue measurement site. The defined surface area shape can include, by way of non-limiting example, a shape that is substantially rectangular, square, circular, oval, or annular, among others.

According to some embodiments, the optical physiological measurement system includes an optical filter having a light-absorbing surface that faces the tissue measurement site. The optical filter also has an opening that is configured to allow the spread light, after being attenuated by the tissue measurement site, to be received by the concentrator. In an embodiment, the opening has dimensions, wherein the dimensions of the opening are similar to the defined surface area shape by which the emitted spread light is distributed onto the surface of the tissue measurement site. In an embodiment, the opening has dimensions that are larger than the defined surface area shape by which the emitted spread light is distributed onto the surface of the tissue measurement site. In other embodiments, the dimensions of the opening in the optical filter are not the same as the diffuser opening, but the dimensions are larger than the detector package.

In other embodiments of the present disclosure, the concentrator comprises glass, ground glass, glass beads, opal glass, or a compound parabolic concentrator. In some embodiments the concentrator comprises a cylindrical structure having a truncated circular conical structure on top. The truncated section is adjacent the detector. The light concentrator is structured to receive the emitted optical radiation, after reflection by the tissue measurement site, and to direct the reflected light to the detector.

In accordance with certain embodiments of the present disclosure, the processor is configured to determine an average level of the light detected by the detector. The average level of light is used to determine a physiological parameter in the tissue measurement site.

According to another embodiment, a method to determine a constituent or analyte in a patient's blood is disclosed. The method includes emitting, from an emitter, light of at least one wavelength; spreading, with a diffuser, the emitted light and emitting the spread light from the diffuser to a tissue measurement site; receiving, by a concentrator, the spread light after the spread light has been attenuated by the tissue measurement site; concentrating, by the concentrator, the received light and emitting the concentrated light from the concentrator to a detector; detecting, with the detector, the emitted concentrated light; transmitting, from the detector, a signal responsive to the detected light; receiving, by a processor, the transmitted signal responsive to the detected light; and processing, by the processor, the received signal responsive to the detected light to determine a physiological parameter.

In some embodiments, the method to determine a constituent or analyte in a patient's blood includes filtering, with a light-absorbing detector filter, scattered portions of the emitted spread light. According to an embodiment, the light-absorbing detector filter is substantially rectangular in shape and has outer dimensions in the range of approximately 1-5 cm in width and approximately 2-8 cm in length, and has an opening through which emitted light may pass, the opening having dimensions in the range of approximately 0.25-3 cm in width and approximately 1-7 cm in length. In another embodiment, the light-absorbing detector filter is substantially square in shape and has outer dimensions in the range of approximately 0.25-10 cm^2, and has an opening through which emitted light may pass, the opening having dimensions in the range of approximately 0.1-8 cm^2. In yet another embodiment, the light-absorbing detector filter is substantially rectangular in shape and has outer dimensions of approximately 3 cm in width and approximately 6 cm in length, and has an opening through which emitted light may pass, the opening having dimensions of approximately 1.5 cm in width and approximately 4 cm in length.

In still other embodiments of the method to determine a constituent or analyte in a patient's blood, spreading, with a diffuser, the emitted light and emitting the spread light from the diffuser to a tissue measurement site is performed by at least one of a glass diffuser, a ground glass diffuser, a glass bead diffuser, an opal glass diffuser, and an engineered diffuser. In some embodiments the emitted spread light is emitted with a substantially uniform intensity profile. And in some embodiments, emitting the spread light from the diffuser to the tissue measurement site includes spreading the emitted light so as to define a surface area shape by which the emitted spread light is distributed onto a surface of the tissue measurement site.

According to yet another embodiment, a pulse oximeter is disclosed. The pulse oximeter includes an emitter configured to emit light at one or more wavelengths. The pulse oximeter also includes a diffuser configured to receive the emitted light, to spread the received light, and to emit the spread light directed at a tissue measurement sight. The pulse oximeter also includes a detector configured to detect the emitted spread light after being attenuated by or reflected from the tissue measurement site and to transmit a signal indicative of the detected light. The pulse oximeter also includes a processor configured to receive the transmitted signal and to process the received signal to determine an average absorbance of a blood constituent or analyte in the tissue measurement site over a larger measurement site area than can be performed with a point light source or point detector. In some embodiments, the diffuser is further configured to define a surface area shape by which the emitted spread light is distributed onto a surface of the tissue measurement site, and the detector is further configured to have a detection area corresponding to the defined surface area shape by which the emitted spread light is distributed onto the surface of the tissue measurement site. According to some embodiments, the detector comprises an array of detectors configured to cover the detection area. In still other embodiments, the processor is further configured to determine an average of the detected light.

For purposes of summarizing, certain aspects, advantages and novel features of the disclosure have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the systems, devices and/or methods disclosed herein. Thus, the subject matter of the disclosure herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Throughout the drawings, reference numbers can be re-used to indicate correspondence between referenced ele-

ments. The drawings are provided to illustrate embodiments of the disclosure described herein and not to limit the scope thereof.

FIG. **1** illustrates a conventional approach to two-dimensional pulse oximetry in which the emitter is configured to emit optical radiation as a point optical source.

FIG. **2** illustrates the disclosed three-dimensional approach to pulse oximetry in which the emitted light irradiates a substantially larger volume of tissue as compared to the point source approach described with respect to FIG. **1**.

FIG. **3** illustrates schematically a side view of a three-dimensional pulse oximetry sensor according to an embodiment of the present disclosure.

FIG. **4**A is a top view of a portion of a three-dimensional pulse oximetry sensor according to an embodiment of the present disclosure.

FIG. **4**B illustrates the top view of a portion of the three-dimensional pulse oximetry sensor shown in FIG. **4**A, with the addition of a tissue measurement site in operational position.

FIG. **5** illustrates a top view of a three-dimensional pulse oximetry sensor according to an embodiment of the present disclosure.

FIG. **6** illustrates a conventional two-dimensional approach to reflective pulse oximetry in which the emitter is configured to emit optical radiation as a point optical source.

FIG. **7**A is a simplified schematic side view illustration of a reflective three-dimensional pulse oximetry sensor according to an embodiment of the present disclosure.

FIG. **7**B is a simplified schematic top view illustration of the three-dimensional reflective pulse oximetry sensor of FIG. **7**A.

FIG. **8** illustrates a block diagram of an example pulse oximetry system capable of noninvasively measuring one or more blood analytes in a monitored patient, according to an embodiment of the disclosure.

DETAILED DESCRIPTION

FIG. **1** illustrates schematically a conventional pulse oximetry sensor having a two-dimensional (2D) approach to pulse oximetry. As illustrated, the emitter **104** is configured to emit optical radiation as a point optical source, i.e., an optical radiation source that has negligible dimensions such that it may be considered as a point. This approach is referred to herein as "two-dimensional" pulse oximetry because it applies a two-dimensional analytical model to the three-dimensional space of the tissue measurement site **102** of the patient. Point optical sources feature a defined, freely selectable, and homogeneous light beam area. Light beams emitted from LED point sources often exhibit a strong focus which can produce a usually sharply-defined and evenly-lit illuminated spot often with high intensity dynamics. Illustratively, when looking at the surface of the tissue measurement site **102** (or "sample tissue"), which in this example is a finger, a small point-like surface area of tissue **204** is irradiated by a point optical source. In some embodiments, the irradiated circular area of the point optical source is in the range between 8 and 150 microns. Illustratively, the emitted point optical source of light enters the tissue measurement site **102** as a point of light. As the light penetrates the depth of the tissue **102**, it does so as a line or vector, representing a two-dimensional construct within a three-dimensional structure, namely the patient's tissue **102**.

Use of a point optical source is believed to reduce variability in light pathlength which would lead to more accurate oximetry measurements. However, in practice, photons do not travel in straight paths. Instead, the light particles scatter, bouncing around between various irregular objects (such as, for example, red blood cells) in the patient's blood. Accordingly, photon pathlengths vary depending on, among other things, their particular journeys through and around the tissue at the measurement site **102**. This phenomenon is referred to as "multiple scattering." In a study, the effects of multiple scattering were examined by comparing the results of photon diffusion analysis with those obtained using an analysis based on the Beer-Lambert law, which neglects multiple scattering in the determination of light pathlength. The study found that that the difference between the average lengths of the paths traveled by red and infrared photons makes the oximeter's calibration curve (based on measurements obtained from normal subjects) sensitive to the total attenuation coefficients of the tissue in the two wavelength bands used for pulse oximetry, as well as to absorption by the pulsating arterial blood.

FIG. **2** illustrates schematically the disclosed systems, devices, and methods to implement three-dimensional (3D) pulse oximetry in which the emitted light irradiates a larger volume of tissue at the measurement site **102** as compared to the 2D point optical source approach described with respect to FIG. **1**. In an embodiment, again looking at the surface of the tissue measurement site **102**, the irradiated surface area **206** of the measurement site **102** is substantially rectangular in shape with dimensions in the range of approximately 0.25-3 cm in width and approximately 1-6 cm in length. In another embodiment, the irradiated surface area **206** of the measurement site **102** is substantially rectangular in shape and has dimensions of approximately 1.5 cm in width and approximately 2 cm in length. In another embodiment, the irradiated surface area **206** of the measurement site **102** is substantially rectangular in shape and has dimensions of approximately 0.5 cm in width and approximately 1 cm in length. In another embodiment, the irradiated surface area **206** of the measurement site **102** is substantially rectangular in shape has dimensions of approximately 1 cm in width and approximately 1.5 cm in length. In yet another embodiment, the irradiated surface area **206** of the measurement site **102** is substantially square in shape and has dimensions in a range of approximately 0.25-9 cm^2. In certain embodiments, the irradiated surface area **206** of the measurement site **102** is within a range of approximately 0.5-2 cm in width, and approximately 1-4 cm in length. Of course a skilled artisan will appreciate that many other shapes and dimensions of irradiated surface area **206** can be used. Advantageously, by irradiating the tissue measurement site **102** with a surface area **206**, the presently disclosed systems, devices, and methods apply a three-dimensional analytical model to the three-dimensional structure being measured, namely, the patient's sample tissue **102**.

According to the Beer-Lambert law, the amount of light absorbed by a substance is proportional to the concentration of the light-absorbing substance in the irradiated solution (i.e., arterial blood). Advantageously, by irradiating a larger volume of tissue **102**, a larger sample size of light attenuated (or reflected) by the tissue **102** is measured. The larger, 3D sample provides a data set that is more representative of the complete interaction of the emitted light as it passes through the patient's blood as compared to the 2D point source approach described above with respect to FIG. **1**. By taking an average of the detected light, as detected over a surface area substantially larger than a single point, the disclosed pulse oximetry systems, devices, and methods will yield a

more accurate measurement of the emitted light absorbed by the tissue, which will lead to a more accurate oxygen saturation measurement.

FIG. **3** illustrates schematically a side view of a pulse oximetry 3D sensor **300** according to an embodiment of the present disclosure. In the illustrated embodiment, the 3D sensor **300** irradiates the tissue measurement site **102** and detects the emitted light, after being attenuated by the tissue measurement site **102**. In other embodiments, for example, as describe below with respect to FIGS. **7**A and **7**B, the 3D sensor **300** can be arranged to detect light that is reflected by the tissue measurement site **102**. The 3D sensor **300** includes an emitter **302**, a light diffuser **304**, a light-absorbing detector filter **306**, a light concentrator **308**, and a detector **310**. In some optional embodiments, the 3D sensor **300** further includes a reflector **305**. The reflector **305** can be a metallic reflector or other type of reflector. Reflector **305** can be a coating, film, layer or other type of reflector. The reflector **305** can serve as a reflector to prevent emitted light from emitting out of a top portion of the light diffuser **304** such that light from the emitter **302** is directed in the tissue rather than escaping out of a side or top of the light diffuser **304**. Additionally, the reflector **305** can prevent ambient light from entering the diffuser **304** which might ultimately cause errors within the detected light. The reflector **305** also prevent light piping that might occur if light from the detector **302** is able to escape from the light diffuser **304** and be pipped around a sensor securement mechanism to detector **310** without passing through the patient's tissue **102**.

The emitter **302** can serve as the source of optical radiation transmitted towards the tissue measurement site **102**. The emitter **302** can include one or more sources of optical radiation, such as LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter **302** includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation. In some embodiments, the emitter **302** transmits optical radiation of red and infrared wavelengths, at approximately 650 nm and approximately 940 nm, respectively. In some embodiments, the emitter **302** includes a single source optical radiation.

The light diffuser **304** receives the optical radiation emitted from the emitter **302** and spreads the optical radiation over an area, such as the area **206** depicted in FIG. **2**. In some embodiments, the light diffuser **304** is a beam shaper that can homogenize the input light beam from the emitter **302**, shape the output intensity profile of the received light, and define the way (e.g., the shape or pattern) the emitted light is distributed to the tissue measurement site **102**. Examples of materials that can be used to realize the light diffuser **304** include, without limitation, a white surface, glass, ground glass, glass beads, polytetrafluoroethylene (also known as Teflon®, opal glass, and greyed glass, to name a few. Additionally, engineered diffusers can be used to realize the diffuser **304** by providing customized light shaping with respect to intensity and distribution. Such diffusers can, for example, deliver substantially uniform illumination over a specified target area (such as, for example, irradiated surface area **206**) in an energy-efficient manner. Examples of engineered diffusers can include molded plastics with specific shapes, patterns or textures designed to diffuse the emitter light across the entirety of the patient's tissue surface.

Advantageously, the diffuser **304** can receive emitted light in the form of a point optical source and spread the light to fit a desired surface area on a plane defined by the surface of the tissue measurement site **102**. In an embodiment, the diffuser **304** is made of ground glass which spreads the emitted light with a Gausian intensity profile. In another embodiment the diffuser **304** includes glass beads. In some embodiments, the diffuser **304** is constructed so as to diffuse the emitted light in a Lambertian pattern. A Lambertian pattern is one in which the radiation intensity is substantially constant throughout the area of dispersion. One such diffuser **304** is made from opal glass. Opal glass is similar to ground glass, but has one surface coated with a milky white coating to diffuse light evenly. In an embodiment, the diffuser **304** is capable of distributing the emitted light on the surface of a plane (e.g., the surface of the tissue measurement site **102**) in a predefined geometry (e.g., a rectangle, square, or circle), and with a substantially uniform intensity profile and energy distribution. In some embodiments, the efficiency, or the amount of light transmitted by the diffuser **304**, is greater than 70% of the light emitted by the emitter **302**. In some embodiments, the efficiency is greater than 90% of the emitted light. Other optical elements known in the art may be used for the diffuser **304**.

In an embodiment, the diffuser **304** has a substantially rectangular shape having dimensions within a range of approximately 0.5-2 cm in width and approximately 1-4 centimeters in length. In another embodiment, the substantially rectangular shape of the diffuser **304** has dimensions of approximately 0.5 cm in width and approximately 1 cm in length. In another embodiment, the diffuser's **304** substantially rectangular shape has dimensions of approximately 1 cm in width and approximately 1.5 cm in length. In yet another embodiment, the diffuser **304** has a substantially square shape with dimensions in the range of approximately 0.25-10 cm^2.

The light-absorbing detector filter **306**, which is also depicted in FIG. **4**A in a top view, is a planar surface having an opening **402** through which the emitted light may pass after being attenuated by the tissue measurement site **102**. In the depicted embodiment, the opening **402** is rectangular-shaped, with dimensions substantially similar to the irradiated surface area **206**. According to an embodiment, the light-absorbing detector filter is substantially rectangular in shape and has outer dimensions of 4 cm in width and 8 cm in length, and has an opening through which emitted light may pass, the opening having dimensions of 2 cm in width and 5 cm in length. In another embodiment, the light-absorbing detector filter is substantially rectangular in shape and has outer dimensions in the range of 1-3 cm in width and 2-8 cm in length, and has an opening through which emitted light may pass, the opening having dimensions in the range of 0.25-2 cm in width and 1-4 cm in length. In yet another embodiment, the light-absorbing detector filter is substantially rectangular in shape and has outer dimensions of 3 cm in width and 6 cm in length, and has an opening through which emitted light may pass, the opening having dimensions of 1.5 cm in width and 4 cm in length.

The top surface of the light-absorbing filter **306** (facing the tissue measurement site **102** and the emitter **302**) is coated with a material that absorbs light, such as, for example, black pigment. Many other types of light-absorbing materials are well known in the art and can be used with the detector filter **306**. During operation, light emitted from the emitter **302** can reflect off of the tissue measurement site **102** (or other structures within the 3D sensor **300**) to neighboring portions of the 3D sensor **300**. If those neighboring portions of the 3D sensor **300** possess reflective surfaces, then the light can reflect back to the tissue measurement site **102**, progress through the tissue and arrive at the detector **310**. Such multiple scattering can result in detecting photons whose pathlengths are considerably lon-

ger than most of the light that is detected, thereby introducing variations in pathlength which will affect the accuracy of the measurements of the pulse oximetry 3D sensor **300**. Advantageously, the light-absorbing filter **306** reduces or eliminates the amount of emitted light that is reflected in this manner because it absorbs such reflected light, thereby stopping the chain of scattering events. In certain embodiments, the sensor-facing surfaces of other portions of the 3D sensor **300** are covered in light-absorbing material to further decrease the effect of reflective multiple scattering.

The light concentrator **308** is a structure to receive the emitted optical radiation, after attenuation by the tissue measurement site **102**, to collect and concentrate the dispersed optical radiation, and to direct the collected and concentrated optical radiation to the detector **310**. In an embodiment, the light concentrator **308** is made of ground glass or glass beads. In some embodiments, the light concentrator **308** includes a compound parabolic concentrator.

As described above with respect to FIG. **1**, the detector **310** captures and measures light from the tissue measurement site **102**. For example, the detector **310** can capture and measure light transmitted from the emitter **302** that has been attenuated by the tissue in the measurement site **102**. The detector **310** can output a detector signal responsive to the light captured or measured. The detector **310** can be implemented using one or more photodiodes, phototransistors, or the like. In addition, a plurality of detectors **310** can be arranged in an array with a spatial configuration corresponding to the irradiated surface area **206** to capture the attenuated or reflected light from the tissue measurement site.

Referring to FIG. **4**A, a top view of a portion of the 3D sensor **300** is provided. The light-absorbing detector filter **306** is illustrated having a top surface coated with a light-absorbing material. The light-absorbing material can be a black opaque material or coating or any other dark color or coating configured to absorb light. Additionally, a rectangular opening **402** is positioned relative to the light concentrator **308** (shown in phantom) and the detector **310** such that light may pass through the rectangular opening **402**, into the light concentrator **308**, and to the detector **310**. FIG. **4**B illustrates the top view of a portion of the 3D sensor **300** as in FIG. **4**A, with the addition of the tissue measurement site **102** in operational position. Accordingly, the rectangular opening **402**, the light concentrator **308** and the detector **310** are shown in phantom as being under the tissue measurement site **102**. In FIGS. **4**A and **4**B, the light concentrator **308** is shown to have dimensions significantly larger than the dimensions of the rectangular opening **402**. In other embodiments, the dimensions of the light concentrator **308**, the rectangular opening **402**, and the irradiated surface area **206** are substantially similar.

FIG. **5** illustrates a top view of a 3D pulse oximetry sensor **500** according to an embodiment of the present disclosure. The 3D sensor **500** is configured to be worn on a patient's finger **102**. The 3D sensor **500** includes an adhesive substrate **502** having front flaps **504** and rear flaps **506** extending outward from a center portion **508** of the 3D sensor **500**. The center portion **508** includes components of the 3D pulse oximetry sensor **300** described with respect to FIGS. **3**, **4**A and **4**B. On the front side of the adhesive substrate **502** the emitter **302** and the light diffuser **304** are positioned. On the rear side of the adhesive substrate **502** the light-absorbent detector filter **306**, the light concentrator **308** and the detector **310** are positioned. In use, the patient's finger serving as the tissue measurement site **102** is positioned over the rectangular opening **402** such that when the front portion of the adhesive substrate is folded over on top of the patient's finger **102**, the emitter **302** and the light diffuser **304** are aligned with the measurement site **102**, the filter **306**, the light concentrator **308** and the detector **310**. Once alignment is established, the front and rear flaps **504**, **506** can be wrapped around the finger measurement site **102** such that the adhesive substrate **502** provides a secure contact between the patient's skin and the 3D sensor **500**. FIG. **5** also illustrates an example of a sensor connector cable **510** which is used to connect the 3D sensor **500** to a monitor **809**, as described with respect to FIG. **8**.

FIG. **6** is a simplified schematic illustration of a conventional, 2D approach to reflective pulse oximetry in which the emitter is configured to emit optical radiation as a point optical source. Reflective pulse oximetry is a method by which the emitter and detector are located on the same side of the tissue measurement site **102**. Light is emitted into a tissue measurement site **102** and attenuated. The emitted light passes into the tissue **102** and is then reflected back to the same side of the tissue measurement site **102** as the emitter. As illustrated in FIG. **6**, a depicted reflective 2D pulse oximetry sensor **600** includes an emitter **602**, a light block **606**, and a detector **610**. The light block **606** is necessary because the emitter **602** and the detector **610** are located on the same side of the tissue measurement site **102**. Accordingly, the light block **606** prevents incident emitter light, which did not enter the tissue measurement site **102**, from arriving at the detector **610**. The depicted 2D pulse oximetry sensor **600** is configured to emit light as a point source. As depicted in FIG. **6**, a simplified illustration of the light path **620** of the emitted light from the emitter **602**, through the tissue measurement site **102**, and to the detector **610** is provided. Notably, a point source of light is emitted, and a point source of light is detected. As discussed above with respect to FIG. **1**, use of a point optical source can result in substantial measurement error due to pathlength variability resulting from the multiple scatter phenomenon. The sample space provided by a 2D point optical emitter source is not large enough to account for pathlength variability, which will skew measurement results.

FIGS. **7**A and **7**B are simplified schematic side and top views, respectively, of a 3D reflective pulse oximetry sensor **700** according to an embodiment of the present disclosure. In the illustrated embodiment, the 3D sensor **700** irradiates the tissue measurement site **102** and detects the emitted light that is reflected by the tissue measurement site **102**. The 3D sensor **700** can be placed on a portion of the patient's body that has relatively flat surface, such as, for example a wrist, because the emitter **702** and detector **710** are on located the same side of the tissue measurement site **102**. The 3D sensor **700** includes an emitter **702**, a light diffuser **704**, a light block **706**, a light concentrator **708**, and a detector **710**.

As previously described, the emitter **702** can serve as the source of optical radiation transmitted towards the tissue measurement site **102**. The emitter **702** can include one or more sources of optical radiation. Such sources of optical radiation can include LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter **702** includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation. In some embodiments, the emitter **702** transmits optical radiation of red and infrared wavelengths, at approximately 650 nm and approximately 940 nm, respectively. In some embodiments, the emitter **702** includes a single source of optical radiation.

The light diffuser **704** receives the optical radiation emitted from the emitter **702** and homogenously spreads the optical radiation over a wide, donut-shaped area, such as the

area outlined by the light diffuser **704** as depicted in FIG. **7**B. Advantageously, the diffuser **704** can receive emitted light in the form of a 2D point optical source (or any other form) and spread the light to fit the desired surface area on a plane defined by the surface of the tissue measurement site **102**. In an embodiment, the diffuser **704** is made of ground glass or glass beads. A skilled artisan will understand that may other materials can be used to make the light diffuser **704**.

The light blocker **706** includes an annular ring having a cover portion **707** sized and shaped to form a light isolation chamber for the light concentrator **708** and the detector **710**. (For purposes of illustration, the light block cover **707** is not illustrated in FIG. **7**B.) The light blocker **706** and the cover **707** can be made of any material that optically isolates the light concentrator **708** and the detector **710**. The light isolation chamber formed by the light blocker **706** and cover **707** ensures that the only light detected by the detector **710** is light that is reflected from the tissue measurement site.

The light concentrator **708** is a cylindrical structure with a truncated circular conical structure on top, the truncated section of which of which is adjacent the detector **710**. The light concentrator **708** is structured to receive the emitted optical radiation, after reflection by the tissue measurement site **102**, and to direct the reflected light to the detector **710**. In an embodiment, the light concentrator **708** is made of ground glass or glass beads. In some embodiments, the light concentrator **708** includes a compound parabolic concentrator.

As previously described, the detector **710** captures and measures light from the tissue measurement site **102**. For example, the detector **710** can capture and measure light transmitted from the emitter **702** that has been reflected from the tissue in the measurement site **102**. The detector **710** can output a detector signal responsive to the light captured or measured. The detector **710** can be implemented using one or more photodiodes, phototransistors, or the like. In addition, a plurality of detectors **710** can be arranged in an array with a spatial configuration corresponding to the irradiated surface area depicted in FIG. **7**B by the light concentrator **708** to capture the reflected light from the tissue measurement site.

Advantageously, the light path **720** illustrated in FIG. **7**A depicts a substantial sample of reflected light that enter the light isolation chamber formed by the light blocker **706** and cover **707**. As previously discussed, the large sample of reflected light (as compared to the reflected light collected using the 2D point optical source approach) provides the opportunity to take an average of the detected light, to derive a more accurate measurement of the emitted light absorbed by the tissue, which will lead to a more accurate oxygen saturation measurement.

Referring now to FIG. **7**B, a top view of the 3D sensor **700** is illustrated with both the emitter **702** and the light blocker cover **707** removed for ease of illustration. The outer ring illustrates the footprint of the light diffuser **704**. As light is emitted from the emitter **702** (not shown in FIG. **7**B), it is diffused homogenously and directed to the tissue measurement site **102**. The light blocker **706** forms the circular wall of a light isolation chamber to keep incident light from being sensed by the detector **710**. The light blocker cover **707** blocks incidental light from entering the light isolation chamber from above. The light concentrator **710708** collects the reflected light from the tissue measurement site **102** and funnels it upward toward the detector **710** at the center of the 3D sensor **700**.

FIG. **8** illustrates an example of an optical physiological measurement system **800**, which may also be referred to herein as a pulse oximetry system **800**. In certain embodiments, the pulse oximetry system **800** noninvasively measures a blood analyte, such as oxygen, carboxyhemoglobin, methemoglobin, total hemoglobin, glucose, proteins, lipids, a percentage thereof (e.g., saturation), pulse rate, perfusion index, oxygen content, total hemoglobin, Oxygen Reserve Index™ (ORI™) or many other physiologically relevant patient characteristics. These characteristics can relate to, for example, pulse rate, hydration, trending information and analysis, and the like. The system **800** can also measure additional blood analytes and/or other physiological parameters useful in determining a state or trend of wellness of a patient.

The pulse oximetry system **800** can measure analyte concentrations at least in part by detecting optical radiation attenuated by tissue at a measurement site **102**. The measurement site **102** can be any location on a patient's body, such as a finger, foot, earlobe, wrist, forehead, or the like.

The pulse oximetry system **800** can include a sensor **801** (or multiple sensors) that is coupled to a processing device or physiological monitor **809**. In an embodiment, the sensor **801** and the monitor **809** are integrated together into a single unit. In another embodiment, the sensor **801** and the monitor **809** are separate from each other and communicate with one another in any suitable manner, such as via a wired or wireless connection. The sensor **801** and monitor **809** can be attachable and detachable from each other for the convenience of the user or caregiver, for ease of storage, sterility issues, or the like.

In the depicted embodiment shown in FIG. **8**, the sensor **801** includes an emitter **804**, a detector **806**, and a front-end interface **808**. The emitter **804** can serve as the source of optical radiation transmitted towards measurement site **102**. The emitter **804** can include one or more sources of optical radiation, such as light emitting diodes (LEDs), laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter **804** includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation.

The pulse oximetry system **800** also includes a driver **811** that drives the emitter **804**. The driver **111** can be a circuit or the like that is controlled by the monitor **809**. For example, the driver **811** can provide pulses of current to the emitter **804**. In an embodiment, the driver **811** drives the emitter **804** in a progressive fashion, such as in an alternating manner. The driver **811** can drive the emitter **804** with a series of pulses for some wavelengths that can penetrate tissue relatively well and for other wavelengths that tend to be significantly absorbed in tissue. A wide variety of other driving powers and driving methodologies can be used in various embodiments. The driver **811** can be synchronized with other parts of the sensor **801** to minimize or reduce jitter in the timing of pulses of optical radiation emitted from the emitter **804**. In some embodiments, the driver **811** is capable of driving the emitter **804** to emit optical radiation in a pattern that varies by less than about 10 parts-per-million.

The detector **806** captures and measures light from the tissue measurement site **102**. For example, the detector **806** can capture and measure light transmitted from the emitter **804** that has been attenuated or reflected from the tissue at the measurement site **102**. The detector **806** can output a detector signal **107** responsive to the light captured and measured. The detector **806** can be implemented using one

or more photodiodes, phototransistors, or the like. In some embodiments, a detector **806** is implemented in detector package to capture and measure light from the tissue measurement site **102** of the patient. The detector package can include a photodiode chip mounted to leads and enclosed in an encapsulant. In some embodiments, the dimensions of the detector package are approximately 2 square centimeters. In other embodiments, the dimensions of the detector package are approximately 1.5 centimeters in width and approximately 2 centimeters in length.

The front-end interface **808** provides an interface that adapts the output of the detectors **806**, which is responsive to desired physiological parameters. For example, the front-end interface **808** can adapt the signal **807** received from the detector **806** into a form that can be processed by the monitor **809**, for example, by a signal processor **810** in the monitor **809**. The front-end interface **808** can have its components assembled in the sensor **801**, in the monitor **809**, in a connecting cabling (if used), in combinations of the same, or the like. The location of the front-end interface **808** can be chosen based on various factors including space desired for components, desired noise reductions or limits, desired heat reductions or limits, and the like.

The front-end interface **808** can be coupled to the detector **806** and to the signal processor **810** using a bus, wire, electrical or optical cable, flex circuit, or some other form of signal connection. The front-end interface **808** can also be at least partially integrated with various components, such as the detectors **806**. For example, the front-end interface **808** can include one or more integrated circuits that are on the same circuit board as the detector **806**. Other configurations can also be used.

As shown in FIG. **8**, the monitor **909** can include the signal processor **810** and a user interface, such as a display **812**. The monitor **809** can also include optional outputs alone or in combination with the display **812**, such as a storage device **814** and a network interface **816**. In an embodiment, the signal processor **810** includes processing logic that determines measurements for desired analytes based on the signals received from the detector **806**. The signal processor **810** can be implemented using one or more microprocessors or sub-processors (e.g., cores), digital signal processors, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), combinations of the same, and the like.

The signal processor **810** can provide various signals that control the operation of the sensor **801**. For example, the signal processor **810** can provide an emitter control signal to the driver **811**. This control signal can be useful in order to synchronize, minimize, or reduce jitter in the timing of pulses emitted from the emitter **804**. Accordingly, this control signal can be useful in order to cause optical radiation pulses emitted from the emitter **804** to follow a precise timing and consistent pattern. For example, when a transimpedance-based front-end interface **808** is used, the control signal from the signal processor **810** can provide synchronization with an analog-to-digital converter (ADC) in order to avoid aliasing, cross-talk, and the like. As also shown, an optional memory **813** can be included in the front-end interface **808** and/or in the signal processor **810**. This memory **813** can serve as a buffer or storage location for the front-end interface **808** and/or the signal processor **810**, among other uses.

The user interface **812** can provide an output, e.g., on a display, for presentation to a user of the pulse oximetry system **800**. The user interface **812** can be implemented as a touch-screen display, a liquid crystal display (LCD), an organic LED display, or the like. In alternative embodiments, the pulse oximetry system **800** can be provided without a user interface **812** and can simply provide an output signal to a separate display or system.

The storage device **814** and a network interface **816** represent other optional output connections that can be included in the monitor **809**. The storage device **814** can include any computer-readable medium, such as a memory device, hard disk storage, EEPROM, flash drive, or the like. The various software and/or firmware applications can be stored in the storage device **814**, which can be executed by the signal processor **810** or another processor of the monitor **809**. The network interface **816** can be a serial bus port (RS-232/RS-485), a Universal Serial Bus (USB) port, an Ethernet port, a wireless interface (e.g., WiFi such as any 802.1x interface, including an internal wireless card), or other suitable communication device(s) that allows the monitor **809** to communicate and share data with other devices. The monitor **809** can also include various other components not shown, such as a microprocessor, graphics processor, or controller to output the user interface **812**, to control data communications, to compute data trending, or to perform other operations.

Although not shown in the depicted embodiment, the pulse oximetry system **800** can include various other components or can be configured in different ways. For example, the sensor **801** can have both the emitter **804** and detector **806** on the same side of the tissue measurement site **102** and use reflectance to measure analytes.

Although the foregoing disclosure has been described in terms of certain preferred embodiments, many other variations than those described herein will be apparent to those of ordinary skill in the art.

Conditional language used herein, such as, among others, "can," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment. The terms "comprising," "including," "having," and the like are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations, and so forth. Also, the term "or" is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term "or" means one, some, or all of the elements in the list. Further, the term "each," as used herein, in addition to having its ordinary meaning, can mean any subset of a set of elements to which the term "each" is applied.

While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the systems, devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, certain embodiments of the disclosure described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others.

The term "and/or" herein has its broadest, least limiting meaning which is the disclosure includes A alone, B alone, both A and B together, or A or B alternatively, but does not require both A and B or require one of A or one of B. As used herein, the phrase "at least one of" A, B, "and" C should be construed to mean a logical A or B or C, using a non-exclusive logical or.

The apparatuses and methods described herein may be implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are nonvolatile memory, magnetic storage, and optical storage. Although the foregoing disclosure has been described in terms of certain preferred embodiments, other embodiments will be apparent to those of ordinary skill in the art from the disclosure herein. Additionally, other combinations, omissions, substitutions and modifications will be apparent to the skilled artisan in view of the disclosure herein. Accordingly, the present invention is not intended to be limited by the description of the preferred embodiments, but is to be defined by reference to claims.

Additionally, all publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application were specifically and individually indicated to be incorporated by reference.

What is claimed is:

1. A physiological monitoring device comprising:

a plurality of emitters configured to emit light in a first shape;

a material positioned between the plurality of emitters and a tissue measurement site on a wrist of a user when the physiological monitoring device is in use, the material configured to change the first shape into a second shape by which the light emitted from one or more of the plurality of emitters is projected towards a surface of the tissue measurement site;

a plurality of detectors configured to detect at least a portion of the light after passing through tissue, the plurality of detectors further configured to output at least one signal responsive to the detected light;

a surface comprising a dark-colored coating, the surface positioned between the plurality of detectors and the tissue when the physiological monitoring device is in use, wherein an opening defined in the dark-colored coating is configured to allow at least a portion of light reflected from the tissue to pass through the surface;

a light block configured to prevent at least a portion of the light emitted from the plurality of emitters from reaching the plurality of detectors without first reaching the tissue; and

a processor configured to receive and process one or more signals responsive to the at least one outputted signal and determine a physiological parameter of the user responsive to the one or more signals.

2. The physiological monitoring device of claim **1**, further comprising a display configured to present visual feedback responsive to the determined physiological parameter.

3. The physiological monitoring device of claim **2**, wherein the display is a touch-screen display.

4. The physiological monitoring device of claim **1**, wherein the plurality of emitters and the plurality of detectors are arranged in a reflectance measurement configuration.

5. The physiological monitoring device of claim **1**, wherein the plurality of detectors are arranged in an array having a spatial configuration corresponding to a shape of a portion of the tissue measurement site bounded by the light block.

6. The physiological monitoring device of claim **1**, wherein the light block comprises an at least partially circular shape, and wherein the plurality of emitters are positioned outside the light block and the plurality of detectors are positioned inside the light block.

7. The physiological monitoring device of claim **1**, wherein the physiological parameter comprises pulse rate.

8. The physiological monitoring device of claim **1**, wherein the physiological parameter comprises oxygen saturation.

9. The physiological monitoring device of claim **1**, wherein the material comprises plastic.

10. The physiological monitoring device of claim **1**, wherein the material comprises glass.

11. The physiological monitoring device of claim **1**, wherein the second shape comprises a circular geometry.

12. The physiological monitoring device of claim **1**, wherein the opening defined in the dark-colored coating comprises a width and a length, and wherein the width is larger than the length.

13. The physiological monitoring device of claim **1**, wherein the dark-colored coating comprises black.

14. A physiological monitoring device comprising:

a plurality of optical sources configured to emit light proximate a wrist of a user;

a diffuser configured to be positioned between the plurality of optical sources and a tissue measurement site on the wrist of the user when the physiological monitoring device is in use;

a light block having a circular shape;

a plurality of detectors configured to detect at least a portion of the light after the light passes through a portion of the tissue measurement site bounded by the light block, wherein the plurality of detectors are arranged in an array having a spatial configuration corresponding to a shape of the portion of the tissue measurement site bounded by the circular shaped light block, wherein the plurality of detectors are further configured to output at least one signal responsive to the detected light, and wherein the plurality of optical sources and the plurality of detectors are arranged in a reflectance measurement configuration;

wherein the light block is configured to prevent at least a portion of light emitted from the plurality of optical sources from reaching the plurality of detectors without first reaching tissue;

a processor configured to receive and process one or more signals responsive to the at least one outputted signal and determine a physiological parameter of the user responsive to the one or more signals; and

wherein the physiological monitoring device is configured to transmit physiological parameter data to a separate processor.

15. The physiological monitoring device of claim **14**, wherein the plurality of optical sources are positioned outside the light block and the plurality of detectors are positioned inside the light block.

16. The physiological monitoring device of claim **14**, wherein the physiological parameter comprises pulse rate.

17. The physiological monitoring device of claim **14**, wherein the physiological parameter comprises oxygen saturation.

18. The physiological monitoring device of claim **14**, wherein the plurality of optical sources are configured to emit light in a first shape, and wherein the diffuser comprises a material configured to change the first shape into a second shape by which the light emitted from one or more of the plurality of optical sources is projected towards the tissue measurement site.

19. A system configured to measure one or more physiological parameters of a user, the system comprising:

a physiological monitoring device comprising:

a plurality of emitters configured to emit light in a first shape;

a material positioned between the plurality of emitters and a tissue measurement site when the physiological monitoring device is in use, the material configured to change the first shape into a second shape by which the light emitted from one or more of the plurality of emitters is projected towards the tissue measurement site;

a plurality of detectors configured to detect at least a portion of the light passing through tissue, the plurality of detectors further configured to output at least one signal responsive to the detected light;

a surface comprising a dark-colored coating, the surface positioned between the plurality of detectors and the tissue when the physiological monitoring device is in use, wherein an opening defined in the dark-colored coating is configured to allow at least a portion of light reflected from the tissue to pass through the surface;

a light block configured to prevent at least a portion of light from the plurality of emitters from reaching the plurality of detectors without first reaching the tissue; and

a processor configured to receive and process one or more signals responsive to the outputted at least one signal and determine a physiological parameter of the user responsive to the one or more signals; and

a processing device configured to wirelessly receive physiological parameter data from the physiological monitoring device, wherein the processing device comprises a user interface, a storage device, and a network interface configured to wirelessly communicate with the physiological monitoring device, and wherein the user interface includes a touch-screen display configured to present visual feedback responsive to the physiological parameter data.

20. The system of claim **19**, wherein the system is configured to determine a state of wellness of the user based on the determined physiological parameter.

21. The system of claim **19**, wherein the system is configured to determine a trend of wellness of the user based on the determined physiological parameter.

22. The system of claim **19**, wherein the visual feedback presented by the touch-screen display is responsive to at least one of a pulse rate and an oxygen saturation of the user.

23. The system of claim **19**, wherein the material comprises at least one of glass and plastic.

24. The system of claim **19**, wherein the second shape comprises a width and a length, and wherein the width is different from the length.

25. The system of claim **19**, wherein the plurality of detectors are arranged in an array having a spatial configuration corresponding to a shape of a portion of the tissue measurement site bounded by the light block.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 10,722,159 B2
APPLICATION NO. : 16/791963
DATED : July 28, 2020
INVENTOR(S) : Ammar Al-Ali

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

On Page 10, Column 1, Item (56), Line 7, under Other Publications, delete “Hear” and insert --Heart--.

On Page 10, Column 2, Item (56), Line 66, under Other Publications, delete “SPo2” and insert --SpO2--.

On Page 11, Column 1, Item (56), Line 1, under Other Publications, delete “Cigilant” and insert --Vigilant--.

On Page 11, Column 1, Item (56), Line 34, under Other Publications, delete “Placementon” and insert --Placement on--.

On Page 11, Column 1, Item (56), Line 57, under Other Publications, delete “Conferemce” and insert --Conference--.

On Page 11, Column 2, Item (56), Line 12, under Other Publications, delete “Depolyable,” and insert --Deployable,--.

On Page 11, Column 2, Item (56), Line 38, under Other Publications, delete “Microoptic” and insert --Micro optic--.

In the Drawings

On Sheet 7 of 7, FIG. 8, Reference Number 810, Line 2, delete “PROCESOR” and insert --PROCESSOR--.

Signed and Sealed this
Eighth Day of September, 2020

Andrei Iancu
Director of the United States Patent and Trademark Office

In the Specification

In Column 1, Line 33, delete "C," and insert --C_i,--.

In Column 1, Line 37, delete "$\varepsilon_{1,\lambda}$" and insert --$\varepsilon_{i,\lambda}$--.

In Column 1, Line 37, delete "A." and insert --λ.--.

In Column 1, Line 42 (Approx.), delete "$\mu_{a,\lambda}$" and insert --$\mu_{\alpha,\lambda}$--.

In Column 7, Line 52, delete "(also" and insert --also--.

In Column 8, Line 1, delete "Gausian" and insert --Gaussian--.

In Column 11, Line 64, delete "710708" and insert --708--.

In Column 12, Line 37, delete "light emitting" and insert --light-emitting--.